Soil responses to sodicity and salinity: challenges and opportunities.

J.D. Oster and I. Shainberg

Abstract/Summary

Exchangeable sodium and low salinity deteriorate the permeability of soils to air and water. The susceptibility of soils to sodicity and low salinity depend on both: 1) the inherent properties of the soils (e.g. texture, mineralogy, pH, CaCO3, sesquioxides, organic matter content and pH) and 2) extrinsic time dependent properties such as cultivation, irrigation method and wetting rate, and the time since cultivation (=aging time). Whereas the effect of inherent soil properties on the soil response to sodicity has been studied and modeled, especially under laboratory conditions, the effect of soil management on the physical response of soils to sodicity has been studied very little. Consequently our ability to predict the changes in soil permeability under field conditions is limited. Including the effect of management on the physical response of soils to sodicity and low salinity is the main challenge facing researchers, consultants and farmers.

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Introduction

Currently available research information and computer models provide only a limited ability to predict the impacts of soil sodicity and salinity on the permeability of soil to air and water. To a large extent this stems from two reasons: 1. Laboratory methods used to obtain data do not reflect the conditions that usually occur in the field (Shaw et al. 1998). Most of the laboratory studies that dealt with salinity and sodicity impacts on soil permeability were done in the laboratory using methods (disturbed and dry samples, fast wetting, no aging, flooding or high intensity rain) that enhanced aggregate slaking, clay swelling and dispersion mechanisms (Shainberg et al., this issue). 2. Inherent problems with modeling processes responsible for *changes in soil pore structure – the spatial arrangements among sand, silt,* clay and organic matter --- that can occur, by whatever process that can change them. These processes include clay swelling and dispersion as a result of changes in soil chemistry, aggregate slaking upon wetting, root growth and decay, vehicle and animal traffic, tillage, and cropping.

There is an increasing obligation to better characterize the response of field soils to salinity and sodicity, and the effect of management on these responses. This is particularly the case for irrigated agriculture. It needs to increase production with less water, in many instances with higher salinity and sodicity, and at the same time to reduce and control negative environmental impacts on surface and ground waters (El-Ashry and Duda, 1999).

Soil responses to sodicity and salinity

The diffuse double layer only partially explains the effect of sodicity and salinity on soil permeability (Quirk and Schofield, 1955; Quirk, 1994; Rengasamy and Sumner, 1998). With increasing sodicity or decreasing salinity, the repulsion forces between clay particles increase. At some level of sodicity and salinity along this continuum, which is unique for each soil (Pratt and Suarez, 1990), clay swelling and dispersion occurs. Clay swelling into the water conducting pores, and clay movement and deposition within the pores are two mechanisms responsible for permeability deterioration. The impacts of these mechanisms are affected by several soil factors: texture, clay mineralogy, organic matter, $CaCO_3$ sesquioxides and pH (Levy et al., 1998).

In the 1980's, researchers proposed that salinity and sodicity also impacted aggregate disintegration (slaking) (Cass and Sumner, 1982; Abu-Sharar et al., 1987). Soil permeability to water and air depends on the amount and continuity of macropores (> 30) in the soil. Upon wetting, slaking of macroaggregates (> 250 μm) into microaggregates (20-200 μm) reduces the amount of macropores which limits soil permeability. Slaking depends on aggregate stability, in addition to the effect of soil sodicity and low salinity. In semiarid regions, where organic matter content is low, aggregate stability increases with increase in clay content, which acts as cementing material (Kemper and Koch, 1966).

Aggregate stability depends also on time dependent variables such as the wetting rate of the aggregates (Quirk and Panabokke, 1962; Mamedov et al., 2001), the antecedent moisture content (Kemper and Rosenau, 1984), and aging, the time cohesion forces have to develop (Kemper et al., 1987). Under no-till (Phillips and Phillips, 1984), or pasture (Greacen, 1958), aggregate stability increases with time and the susceptibility of soils to an unfavorable combination of sodicity and salinity decreases (Shainberg et al., 2001). Aggregates are more stable and less susceptible to sodicity when exposed to wetting rates less than 10 mm/hr (Shainberg et al., 2001; Mamedov et al., 2001). This effect of wetting rate is greater for clay soils than for sandy soils. The role of antecedent water content stems from its influence on the rate cohesive forces develop that help stabilize soil aggregates. Development occurs faster in moist soils compared with dry or saturated soils (Kemper and Reserau, 1984; Kemper et al., 1987). This aging effect, which increases with clay content, decreases the susceptibility of soils to unfavorable combinations of sodicity and salinity. Since permeability depends on both the distribution of soil particles within the soil matrix and on aggregate stability, so also the effect of salinity and sodicity permeability of soils depends on soil, water and crop management.

Challenges and opportunities

Use of more saline/sodic irrigation waters, such as municipal wastewaters and irrigation drainage waters will accelerate in the future. So will the reuse of more saline/sodic drainage waters generated by irrigation in order to reduce environmental impacts on receiving waters (Tanji and

Karajeh, 1993; Oster, 1994). This will generate a need to modify existing soil and crop management practices, or to develop new practices in order to cope with the inevitable increases in salinity and sodicity that will occur. Consequently, the interaction between soil management and soil sodicity under different levels of salinity will continue to be a challenge for researchers and farmers.

An important aspect of soil management is the recognition of the different responses of surface and subsurface soils to sodicity and salinity (Oster and Jayawardane, 1998). Surface soils, because of their position, and often tillage, are affected more than subsoils by water drop impact, rapid wetting, irrigation water quality, animal and vehicular traffic, tillage, and surface mulches. The bonding mechanisms associated with organic matter (Nelsen and Oades, 1998) and aging are continually changing in surface soils as compared to what occurs in subsoils. Subsoils have lower wetting rates, the water contents prior to wetting are usually higher, the organic matter content is usually lower, and the chemical state of organic matter is more stable than surface soils. Subsoil tillage and amelioration are expensive. Because of these differences, the criteria of acceptable combinations of sodicity and salinity are different for surface and subsurface soils, as are the methods of soil management.

Consideration needs to be given to changing research methods to characterize the impacts of salinity and sodicity to better match what occurs in the field. For example, the differences in water application rates among various irrigation methods likely impact how surface soils respond to sodicity, and consequently the infiltration characteristics of the soil. Vehicle and animal traffic likely have similar effects. For example, 'Will the infiltration rates and grazing management of pastures irrigated with municipal wastewater be different than those irrigated with less saline/sodic channel waters?' is a question that is under consideration at the Institute of Sustainable Irrigated Agriculture at Tatura, Vic. The issue of particular concern is the effect of animal traffic on the physical properties of the surface soil during extended wet periods in the winter rainy season. Irrigation often supplements rainfall, which in turn enhances the negative impacts of sodicity on surface soils almost immediately and eventually on subsurface soils as well if sufficient amounts of rainfall infiltrate. If one overlays different cropping/irrigation systems onto the rainfall issue, the result will be a long list of concerns, which goes beyond the scope of this paper. This diversity is both a challenge and an opportunity in the development of appropriate research strategies and methodologies. This aspect of the future will be enhanced if the research program includes field research and strong linkages with consultants and farm advisors who work directly with farmers to solve problems.

As irrigation with more saline-sodic irrigation waters than was common in the past increases, the assessment of the future sustainability of their use becomes an issue. Relevant field data and on-farm experience is for the most part not available. Under these circumstances one has several options: 1. Use existing data and concepts (Quirk and Schofield, 1955; McNeal and Coleman 1966; Rengasamy and Sumner, 1998; Levy et al., 1998). 2. Use model predictions based on clay swelling (McNeal, 1968) or based on the Equivalent Salt Solution Series concept (Jayawardane, 1992). They all provide insights into what may happen in the future, but all are based on laboratory methods that do not reflect field conditions. We believe that the challenge to modelers (Jayawardane, 1992; Suarez and Simunek, 1997; Arya, et al., 1999a and 1999b) is to incorporate the effect of both soil solution chemistry and soil management into their models. It should be realized that: 1. soil permeability depends on time dependant processes such as aging, cultivation, vehicle and animal traffic, cropping, irrigation, and rainfall, in addition to particle size distribution, clay swelling and dispersion, and 2. the time dependant processes are much more dynamic for surface soils than for subsoils.

Another aspect of assessing future impacts is the need to predict soil solution and exchange composition as a function of irrigation water composition and crop water uptake. Changing the irrigation water quality can result in soil chemistry changes that can require more than a decade to occur. This is particularly true for sodification, an increase in soil sodicity with time. This process is buffered by a nonfavorable cation exchange equilibria (Bolt, 1978). In order to achieve an equilibrium level of exchangeable sodium, the soil exchange phase must be exposed to many more moles of sodium in the soil solution phase than needed to achieve the new exchangeable sodium, or sodicity level. An example of this, based on laboratory data obtained by David Burrow (private communication, 2000), is the change in irrigation from channel water with an EC of 0.1 dS/m and an SAR of 1.3 to irrigation with Mooroopna wastewater with an EC of 0.8 dS/m and an SAR of 6. Changes in sodicity in the 0 - 0.1 m depth interval were projected to be complete in one year as compared to 30 years for the 0.2 - 0.5 m depth interval (Oster, 2000).

The useful aspect of existing hydrosalinity models (Suarez and Dudley, 1997) is that they provide insights into how the chemical composition of the soil solution and exchange phases will change with time for a given change in irrigation water quality. Hydrosalinity models such as UNSATCHEM (Suarez and Simunek, 1997) should be put to use to predict the temporal changes in salinity and sodicity when assessing the potential impacts on soil chemical composition as a result of changing from one irrigation water quality to another. An interesting aspect of UNSATCHEM is that it also predicts the impacts of salinity and sodicity on soil permeability based on the work of McNeal (1968). To our knowledge it is the only model that links both soil chemical and physical properties.

Finally, the use of waste- and drainage-waters can be expected to increase whether key research is complete or not. What are some possible strategies to foster the sustainable use of these waters? 1. Match alternative cropping options to the constraints imposed by the expected levels of salinity, sodicity and water logging (Oster et al., 1999). 2. Encourage the use of economic incentives to foster the long term dedication of lands irrigated with saline/sodic waters to crop production systems that are most likely to be sustainable. Both strategies would reduce the chances of encountering problems with subsoil permeability and the subsequent need for subsoil reclamation.

Concluding comments.

In the future, soil salinities and sodicities will increase to higher levels in irrigated lands than was considered normal in the past. This will result from using irrigation water more efficiently, and from increasing the use of recycled water. In the past, the focus of irrigation management was on soil reclamation to reduce soil salinity and sodicity to acceptable levels, and subsequently on management options to maintain them. There was little regard to environmental impacts related to the disposal of drainage water. This cannot continue to be the case. In addition, future work needs to also focus on soil and crop management strategies to assure irrigation sustainability at higher levels of salinity and sodicity.

Soil salinity and sodicity levels are dynamic: they change with the amount and quality of infiltrated water, evapotranspiration and rainfall. The impact of these changes on soil permeability is only partially predictable because much of the underlying research data obtained in laboratories did not simulate field conditions. The laboratory studies enhanced aggregate slaking as well as the response of soils to clay swelling and dispersion in ways that were not representative of what occurs in the field. Future laboratory and field research needs to address both the inherent soil properties as well as the extrinsic, time dependent properties such as management, cultivation, cropping, and method of irrigation.

The situation in regard to predicting changes in soil chemistry, the chemical composition of the solution and exchange phase, is considerably better than that for predicting changes in soil permeability. The available transient and steady state hydrosalinity models need to be put to use when assessing changes in soil chemistry that can occur with changing irrigation water quality and irrigation efficiency and rainfall. Their use should become common.

Where the linkages between researchers, public and private farm advisors/consultants, and farmers have been strong, everyone has benefited. Useful research information has been put into use quickly, and the research needs of farmers have quickly come to the attention of researchers. These linkages will continue to be needed and fostered as the use of saline and sodic irrigation water becomes a more common occurrence.

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